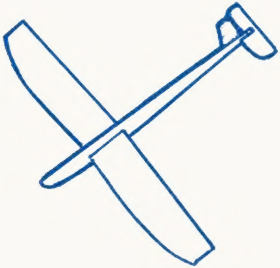
THINGS of science



AERODYNAMICS

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AERODYNAMICS

We live in a sea of air some 200 miles thick. This air which surrounds the earth completely is in constant motion, and although we cannot see it, we often feel it as it moves past us. The air may move quickly or slowly, in circles or in straight lines, and in any direction, up, down or sideways.

Much of our lives is regulated by the movements of the air. They determine the weather, influence the structure of bridges and buildings and the safe travel of airplanes and sailing vessels.

The study of air in motion, known as aerodynamics, is an important branch of science and is a very complex one. It involves a knowledge of engineering and materials, as well as a profound understanding of mathematics.

You have perhaps dreamed of flying high into the air like a bird, soaring out of sight and into the clouds. To some extent we have achieved this with fast-flying planes and jets which transport thousands of people back and forth across the earth. But compared to the bird, man has still a long ways to go to

master the science of flying.

You may be surprised to learn that birds and insects fly completely according to aerodynamic principles and that their movements in the air are controlled by them.

Since we live in a moving atmosphere of air, we too must pay attention to the air and its behavior and yield to aerodynamic influences.

What are these principles and how does understanding them help us make better buildings and better planes, and avoid disasters caused by changing atmospheric conditions?

In this unit, we shall observe some of the effects of air in motion on objects with special reference to the glider.

First identify your specimens.

GLIDER MODEL—In plastic wrapping.

EXTRA GLIDER WING—Flat; eight-inch wing span.

PLASTIC SODA STRAW—Eight inches long.

THIN WHITE PAPER—Two sheets 3 x 8 inches.

HEAVY PAPER—3 x 5 inches.

WHAT MAKES THE AIR MOVE?

As we stand on the beach or walk in an open field, we may feel a pleasant breeze flowing by. Or, if we look at the tree tops, they may be swaying in the wind while we feel no movement in the air below. On a stormy day, the wind may rush by carrying any loose objects along with it. Where does the wind come from and where does it go?

The air is made up of nitrogen, oxygen and a number of other gases and has mass—you can feel it as it passes by—and density—you can weigh it. It exerts a great pressure on the earth's surface—about one ton per square foot— but you cannot grasp it and hold it in your hand—it has no form. Yet it can act like a solid substance and uproot trees and tear ships apart in sea or sky. Air flow may be orderly or laminar, disorderly or turbulent.

Aside from providing us with essential oxygen, air most greatly affects our lives by its movement.

Many factors contribute to air movement. We can demonstrate some of them.

Experiment 1. Cut a strip ⅛ inch wide and 8 inches long from one of your pieces of thin paper. Hold the strip by

one end above the cold surface of a stove. Be sure there is no draft. Note that it hangs limply and quite still.

Now, turn the burner on. If you are using a gas stove, place an asbestos pad or frying pan over the burner for safety. Hold the strip about six inches above the hot surface. Does it move as if in a breeze?

The molecules in the air are in constant motion, bumping into each other and bouncing away continually, their activity depending upon the surrounding temperature. The warmer it is the faster they move. As the air close to the stove becomes heated, the molecules become more agitated. This causes the molecules to strike each other with greater force producing wider spaces between them as they glance away from each other, and the air expands. As the air expands, it becomes less dense and lighter and rises. The colder air above whose molecules are moving about more slowly is denser than the hot air below and therefore heavier. The cold air rushes downward as the hot air rises and fills the space left behind. The air movement resulting from this exchange is called a convection current.

Convection currents occur wherever

there is any slight difference in temperature in the environment.

Similar currents occur in the atmosphere over sun-heated surfaces of the earth, but on a much larger scale. Convection currents create turbulences in the air which may vary from small whirls and eddies to huge bubbles of warm air up to a half mile wide. When bubbles of air rise up into the atmosphere cooler air rushes down to fill the space, causing a strong downdraft of air. This air then becomes heated, forming another bubble which rises up and more cold air streams down. Depending upon conditions, you will have a gentle breeze or a strong wind. Birds and gliders can make use of the updraft of these strong convection currents, called thermals, to lift them up to great heights.

Turbulences caused by thermal convection are more pronounced in the first few thousand feet of altitude.

When the skies are clear and blue with puffs of cumulus clouds here and there, it may look like perfect flying weather to the uninitiated, but actually the air may be very rough. The sun-warmed earth is creating huge convection currents and at the top of each column of rapidly ascending air is a tuft of cumulus cloud.

Updrafts mean downdrafts are somewhere nearby. Thus a cumulus cloud indicates turbulence to the flyer and such clouds are carefully avoided.

The amount of moisture in the air also has an influence on its activity. As the air rises from the earth's surface, it expands and cools at a constant rate if there is no change in the surrounding temperature. Since colder air cannot retain as much moisture as warmer air, some of the moisture in the air condenses. This causes heat to be released and the rising air masses to expand further. The upward movement as a result becomes accelerated and more condensation takes place. If there is much moisture in the air, the cycle continues and the activity of the air becomes violent, and a thunderstorm is born. Air currents thus created may rise at speeds up to 15 to 30 feet per second.

There is yet another cause of turbulence.

Experiment 2. Place the ⅛-inch strip of paper crosswise across the edge of a piece of cardboard about 9 x 12 inches in size, or a similar flat object held perpendicularly, gluing it to the edge at the center (Fig. 1a). Hold the cardboard upright in front of a fan or air conditioner

allowing the air to strike against the lower section of the cardboard. Note what happens to the paper strip (Fig. 1b).

This experiment demonstrates the path a wind takes when it strikes an obstacle like the flat side of a large cliff or a high mountain. It rushes up the side of the obstruction creating a strong updraft.

Experiment 3. Cut another 8-by-⅛-inch strip from the same sheet. Keeping the cardboard in the same position in front of the fan, hold this strip at one end and let it hang just above the level of the mounted strip. How is it affected

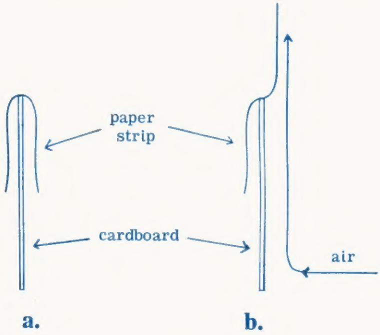

Fig. 1

by the current of air? Can you trace the path of the downdraft?

Hold the strip at different positions behind the obstruction. Note that it falls limp without movement in certain spots. The air does not drop straight down, but descends at a slope, and areas of the air beneath the slope remain little disturbed by the downdraft.

Air like every other substance on earth is subject to gravitational pull and an updraft is always followed by a downdraft.

When air crosses a mountain range, undulating waves are set in motion. The downdrafts in these mountain waves may reach speeds at times of 5,000 feet per minute. Downdrafts such as these are so strong that an airplane traveling parallel to the range can be drawn down to the ground or forced into the side of a mountain.

But if not too strong, these downdrafts can be used by birds and gliders to transport them in their flight through the air.

BERNOULLI'S PRINCIPLE

Aerodynamics is important in many fields of study and technology, but when we refer to it we usually think of airplanes and other airborne vehicles because of its close association with the problems of flight.

Since early times, man aspired to fly in the sky and eventually learned by trial and error and by research what the bird developed naturally through years of evolution. Experimenters discovered early that man could not fly by flapping wings, but also found after many years of study that airplane wings designed like the wings of birds were the most effective for flying.

What makes it possible for an object heavier than air to float with apparent ease among the clouds?

You will find that the rules of physics govern the flight of both bird and man and that planes and birds use basically the same techniques in flying. Among the most important of physical laws applied in aerodynamics is Bernoulli's principle. Let us do some experiments to demonstrate this law which states that as the velocity of a gas or liquid increases, pressure decreases, and as the velocity

decreases, pressure increases.

Experiment 4. Take the two pieces of thin paper in your unit and holding them about an inch apart let them hang lengthwise. Gently blow through the space between them. Do they spread apart or come together? Blow harder. Do they move still closer to each other? The pressure between the strips is reduced as the air speeds through and the pressure of the air on the outer surfaces forces the strips together.

Experiment 5. Cut the second 3 x 8-inch thin paper in half crosswise to give two four-inch pieces. Take one of them and place it across the narrow width inside the top of your THINGS box (Fig. 2).

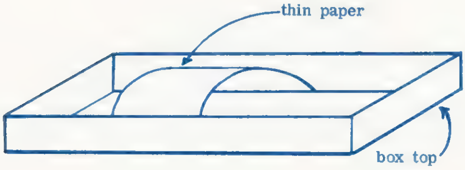

Fig. 2

With your plastic straw, blow a stream of air into the hollow beneath the paper. What happens? The pressure of the air under the paper is decreased as the air rushes through and the paper is flattened against the box top by the air pressure above.

Now blow air horizontally across the curved surface of the paper. What happens to the paper this time? It rises and floats away. The wind you created reduces pressure above the paper and at the same time produces a partial vacuum, causing the paper to rise up. Wind passing across the wing of a plane has a similar effect.

From the above observations can you explain why flat roofs are rather easily blown off by high winds?

The wing of a modern plane is shaped in general similar to the diagram in Figure 3 and is called an airfoil.

Fig. 3

Experiment 6. Curve about one-half inch of one of the 3 x 4-inch sheets of the thin paper over your index finger and hold it secure with your thumb to simulate an airfoil. Keeping your other fingers out of the way by pressing them against your palm, blow straight across the top of the sheet. Does it rise or fall? Blow harder. Can you blow the paper downward by blowing more vigorously across it? The harder you blow the higher it rises. Why?

As the wing of an airplane moves through the atmosphere, the air in front of it is pushed apart, some of it going above and some of it below the wing. After the plane has passed, the molecules go back together again. But because the upper surface of the wing is curved, the molecules of air flowing over the top

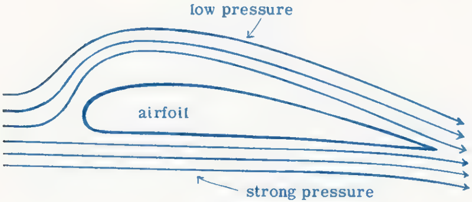

Fig. 4

must travel further and therefore faster than those below to reach the same point (Fig. 4).

According to Bernoulli's law, when air travels faster it exerts less pressure. Therefore, there is less pressure above the wing than below, and a partial vacuum is created. The pressure below pushes the wing upward until the pressure above and below the wing is equalized, providing the necessary lift to keep the plane up in the air.

Birds' wings are shaped in the same way. Although it may seem so, birds do not fly by flapping their wings. At the tips of their wings are special feathers that serve a similar purpose as the propellers in an airplane. When their wings are flapped, these feathers thrust the birds forward by creating a backward push. As the birds go forward, air moves over the curve of their wings creating a low pressure area above them, lifting the birds up, partly by the upward pull of the vacuum produced and partly by the pressure from beneath.

The reduced air pressure above the wing provides more than ⅔ of the lifting force.

Experiment 7. Hold the paper again as in Experiment 6. Blow straight at the

curved surface so that some of the air passes above and some below the paper. The paper pulls away and rises. The wind from below the paper pushes it back and upward as the pressure above is reduced. In a plane, not only the atmospheric pressure, but the force of the air rushing by beneath the wing helps to lift it.

The propeller of an airplane is shaped similar to the wings, with the leading edge thicker than the trailing edge (Fig. 3). As the propeller turns at high speed, it creates a low pressure area in front and pulls the plane forward, while creating a wind over the wings at the same time to provide lift.

Some backward push is also produced. As stated in Newton's Third Law of Motion, every action has an equal and opposite reaction.

Experiment 8. All forward movement results from a movement in the opposite direction. Walk a few steps and observe that as you move forward your foot pushes against the ground. In the same way, as a plane moves upward it also pushes downward.

Experiment 9. Bernoulli's principle has application not only in flight but also in various other aerodynamic fields. You

can show how it is used to provide lift for vehicles that travel on a cushion of air over land or water.

From the stiff paper in your unit cut a circle about the size of a quarter and another about 1/8 inch larger in diameter.

Make a hole the diameter of the plastic straw in the center of the smaller disk.

Cut a two-inch piece off the straw and set it aside for another experiment. Insert the six-inch length into the hole you just

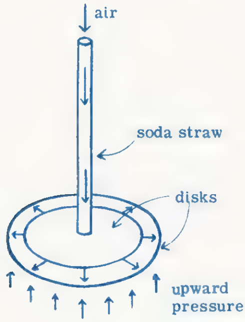

Fig. 5

made. Have the disk flush with the end of the straw. Secure the disk to the straw with tape.

Place the larger disk on the table and holding the disk with the straw just above it, blow hard through the straw. Does the free disk rise up (Fig. 5)?

The air passing rapidly over the lower disk reduces the pressure above it and causes it to rise.

GLIDERS AND AIRPLANES

Identify the parts of the glider: the wing, bent slightly upward; the fuselage, with slots for the wing and the two stabilizers; the smaller vertical stabilizer and the larger horizontal stabilizer, in one piece—separate.

Experiment 10. Assemble your glider carefully. Do not glue the parts together. They must be removable for the experiments. If you find it necessary to secure the wing to keep it in place, use cellophane tape which is easily removed. Be sure to push the wing forward in the slot.

The amount of lift a wing can produce is determined by several factors. First,

the size of the wing. The larger the wing, the greater the amount of lift possible.

Fly your glider straight out, horizontally, and note how it floats down along a slope. It is riding on a hill of air. Since it has no motor like a plane, it must depend upon the air current to carry it along. Because all objects are influenced by the force of gravity, it slopes downward to earth.

Experiment 11. Take your two-inch piece of straw and hold it at the top of your THINGS box held at an inclination of about 30 degrees. Then release it. It rolls downhill, moving forward as well as downward. Without the box, the straw would drop straight down.

The box acts as a barrier to the gravitational pull.

In the same way, your glider rides down a hill of air, pulled forward and downward. The air interferes with the pull of gravity just as the box did under the straw, and the glider slides gently down.

A bird wishing to fly upward, locates a rising current of air and rests on it with wings outspread. The push of the air plus the aerodynamic lift of the bird's wings can keep it afloat for hours without any movement of its wings.

Eventually the bird will reach a height where the air current can no longer lift it up. It then goes off in a glide down a hill of air pulled by gravity, but gently buoyed by the air which prevents it from falling straight down to the earth. When it finds another upward current the bird may soar upward again.

A person on a glider or sailplane, like a bird, can glide for hours in the air just by locating suitable currents.

Experiment 12. Increase the length of the wings in your glider an inch on each end by attaching a piece of the thin paper of the same width as the wing and 1¼ inches long on the tip of each wing with cellophane tape. Does the glider have more lift?

Gliding birds, such as gulls and hawks, have a much wider wingspread than do non-gliders. However, even the non-gliding birds ride the currents of air when they fly from tree to tree.

Experiment 13. If the angle of a wing of an airplane is changed so that the leading edge is tilted higher, or the angle of attack is increased, the lift is increased, according to Bernoulli's law, since the air across the top of the wing must travel faster. The air striking the

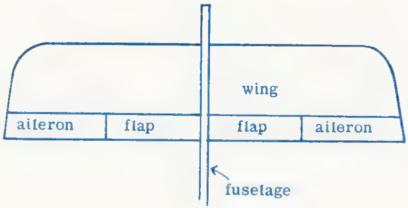

Fig. 6

bottom surface of the wing also contributes to the increased lift. This lift is derived from Newton's Third Law—for each action there must be an equal and opposite action. The forces above and below the wing provide the total lifting force of the plane.

A plane increases its angle of attack by moving the horizontal tail. It increases the lift even more by lowering the flaps along the trailing edge of the wings (Fig. 6).

Simulate flaps on your glider by attaching 1¾ inch by ¾ inch strips of the

thin paper to the inner section of the trailing edge of the wings.

Bend the flaps down just slightly. Does the glider acquire more lift?

If the angle of attack is increased beyond a certain critical point, the lift will disappear and the plane will stall and lose altitude until airspeed is regained.

The lift is produced by decreased pressure above the wing. The partial vacuum thus produced keeps the airstream close to the wing. If the angle of attack is increased too much, the airstream can no longer be held to the wing and breaks away and the lift no longer exists, causing the plane to stall.

To avoid this, small slots are placed near the upper surface of the wing. The air passing through the slots is forced to travel faster creating reduced pressure and the airstream will flow closer to the wing.

Experiment 14. Bend the flaps to about 45 degrees. Now fly it. Does it stall?

Speed is an important factor in lift. The faster a plane or bird flies, the greater the lift produced.

Experiment 15. Thrust your glider into the air gently. Does it travel very

far? Now thrust it with greater force. Does it have more lift and rise higher into the air?

The pull of gravity must always be taken into account. If the upward force of the lift and downward pull of gravity are in equilibrium, an airplane, bird or glider will remain at the same altitude. To climb upward, the lifting force must be greater than the pull of gravity and to travel downward, the lift must be less than gravity.

Most birds take off into the wind. Can you explain why?

At take-off a plane needs a greater lifting force to counteract the gravitational pull. To provide for this, a plane is equipped with flaps to extend the wing surface and travels rapidly along the ground to force the air molecules to pass over the wings fast enough to create the necessary lift.

As an airplane moves through the air it must push air particles out of its way. In doing this, the plane experiences a force called resistance. This resistance is known as drag and opposes the forward motion of the plane. As the airplane flies, the molecules of air slide past each other and rub against each other. This rubbing creates friction and produces

heat which at high speeds may reach temperatures of 200°F or more.

Various factors contribute to drag when a plane is in flight and the structure of planes are so designed to minimize drag and friction as much as possible.

Experiment 16. Attach ailerons to the trailing edge of the wings of your glider and then fly it with both flaps and ailerons extended (Fig. 5). To make the ailerons cut strips of the thin paper about 2 inches long by ¾ inch wide and attach them alongside the flaps. Cut the edge of the ailerons at a slight angle in line with the outer edge of the wing.

Ailerons are used to provide lateral or roll control and are used to tilt the wings when making turns. When a plane is turned, it must be banked or tilted to keep it in control. A pilot wishing to tilt the plane, raises one aileron and lowers the other at the same time. The wing with the aileron pushed up goes downward and the wing with the aileron pushed downward is raised. Why?

Bend the aileron on the right wing down slightly and the one on the left wing slightly up. Fly the glider. Which wing is lowered?

Can you adjust the ailerons so that the glider will bank without crashing?

Experiment 17. To be properly balanced, the wings of a plane or glider must be equal on each side.

What happens when you make one wing even slightly longer than the other? Push the wing about 1/8 inch to the right. What effect does this have on the glider's flight path? In which direction does the glider turn? Why?

Experiment 18. There are as many factors involved in landing a plane as there are in taking off. First of all, the plane must be slowed against the pull of gravity. To do this, the plane's flaps come into action on the wings as well as the elevators on the back of the horizontal stabilizer.

Place a narrow flap like those on the wings along the length of the trailing edge of the horizontal stabilizer to simulate the elevator.

Bend the flaps and elevator down to about 45 degrees. Is the landing of the glider slowed? Change their angles and try to regulate the speed of landing.

Experiment 19. Lower the elevator only. How does this affect its flight? Does raising the elevator upward have any effect on the glider's flight?

Experiment 20. A plane, just like a boat has a rudder behind it to guide it

in the direction desired.

A rudder is hinged to the back of the vertical stabilizer.

Place a one-fourth-inch extension on the back of the vertical stabilizer, exactly in line with it and fly the glider. It should fly straight.

Now bend the rudder to the left and fly the glider. In which direction does it turn? Bend the rudder to the right and fly the glider again. Which way does it turn this time? Regulate the rudder to obtain the exact amount of turn desired.

A plane must above all be stable. It must be able to fly in a straight path at a steady speed and without the aid of a pilot.

Experiment 21. Replace the wing you have on the glider with the extra wing. Note that it is flat and not bent like the original wing. Fly the glider. Does it fly in a straight path? It should.

Now remove the vertical stabilizer. What happens to the glider? It has lost its stability and control is gone.

Replace the vertical stabilizer and remove the horizontal stabilizer. What happens to the glider's stability?

Experiment 22. Reassemble the glider. Push the wing forward in the slot and be sure the wings are exactly balanced.

Place the glider on a small surface such as the flat head of a nail and find the point at which it is in exact balance and will neither fall backward nor forward or sideways, and where it will swing around freely as if on a pivot. This point is its center of gravity. With a pencil make a mark at this point on the glider. Note that the center of gravity is just beneath the center of the wing.

Fly the glider noting how smoothly it sails.

Now push the wing to the back of the slot. Fly it. What happens? It takes a nose dive. Check its center of gravity. By shifting the wing, you changed its center of gravity to the front of the wing.

Push the wing forward into its original position. Cut strips from the heavy paper in one-half inch widths. Wind three or four thicknesses of this paper around the nose of the glider and secure with tape. Find its center of gravity again. Has it moved to the front of the wing? Fly the glider. Does it crash?

Change the center of gravity by placing a weight on the tail of the glider. What happens?

Where is the best location for the center of gravity in your glider? What could happen to a plane if its cargo were

loaded without considering the center of gravity?

Experiment 23. With a sharp instrument make a line across the exact center of the extra wing. Bend the wing upward along this line to form a shallow V-shape. If the wing splits at the center secure it with cellophane tape. The angle formed between two flat or plane surfaces is known as a dihedral angle. In an airplane the angle between the right or left wing inclined upward and a horizontal line drawn laterally from the center of the bottom side of the wing is referred to as the dihedral. Wings inclined upward are called dihedrals.

Insert the inclined wing into the glider. Now fly it. Is it more stable than with the flat wings? Do you get a smoother flight?

The stability of a plane depends upon its ability to resist disturbing forces and maintain its equilibrium while in flight. Inclined wings or dihedrals produce more lift and also provide more stability. They make a plane fly straight instead of circling.

Experiment 24. Raise the sides of the dihedral higher. Does the stability increase or decrease? Can you explain your result?

Experiment 25. Straighten out the

wings and measure inward from the ends of the wing one inch. Cut off the one-inch sections with scissors. Replace the pieces with cellophane tape and tilt the tips upward (Fig. 7).

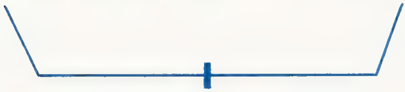

Fig. 7

Replace the wing in the slot and fly the glider again. Does the change in the wing improve its flight?

These experiments demonstrate some of the principles of aerodynamics and their applications.

It is a fascinating field of study related to various aspects of our lives. Many books have been published on the subject and a few of them are listed below for those of you who wish to pursue the subject further.

Elementary physics books.

Aeromodeling, R. H. Waring, Arg Books, New York (1965).

Birds and Planes: How They Fly, Ava Morgan, Thomas Y. Crowell Co., New York (1953).

Mastery of the Air, Sir Graham Sutton, Basic Books, Inc., New York (1966).

Paper Airplane Book, Seymour Simon, Viking Press (1971).

Paper Airplanes: How to Make Airplane Models from Paper, Richard Slade, St. Martin's Press, Inc., New York (1971).

The Physical Nature of Flight, Ray Holland, Jr., W. W. Norton and Company, Inc., New York (1951).

Sailplanes and Soaring, James E. Mrazek, Stackpole Books, Harrisburg, Pa. (1973).

Appreciation is expressed to Russell Greenbaum, Office of Naval Research, Arlington, Va., for reviewing this booklet.

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